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POTENTIAL SOIL MOISTURE DEFICIT AT KEW 1698-1976.

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Summary

Estimates of end-of-August potential soil moisture deficit (psmd A) for Kew obtained from monthly Penman formula estimates of potential evaporation (pe) and daily rainfall data for 1871 to 1976 are analysed; they are also compared with values of an index thereof ("psmd A") obtained from approximations to Penman pe and monthly rainfall totals. The index is shown to be a useful one and its behaviour from 1698 to 1976 is studied. Although there have been fluctuations in pe and in rainfall since 1697/8 no obvious trends appear. There has been a marked increase in the frequency of high values of "psmd A" since 1856 but it is suggested that this is probably due to unavoidable lack of precision in the upward adjustment of pre-1856 rainfall totals to allow for assumed deficiencies of catch.

1. Introduction

Evaporation calculations have been made for Kew from 1871 to 1976 as described by Wales-Smith (1976). Results included end-of-month potential soil moisture deficit (psmd) values obtained from a daily accounting of rainfall and (Penman, 1948) potential evaporation (pe). These derived data are given in Appendix 1. Two restrictions were imposed upon the psmd estimates; (a) that psmd = 0 when 3smd, the 3 inch root constant soil moisture deficit (Penman, 1949) = 0 and (b) that when 3smd does not return to zero during the inclusive period October to February then end-of-February values of psmd are reduced to the corresponding 3smd values. Month-maximum values of psmd can also be readily obtained from the calculations and these are given in Appendix 2.

2. Analysis of psmd 1871-1976

The values and year-dates of the 12 highest values of end-of-May, June, July and August psmd are given in Table 1, together with cumulative probability and return period values following Jenkinson (1969). The month-by-month development of the 12 highest end-of-July and end-of-August psmd totals is shown in Figures 1 and 2. Month-maximum values are plotted where they differ from month-end values.

End-of-June and end-of-August values of psmd are plotted sequentially in Figures 3 and 4 together with decadal means. (Decadal means shown X and plotted to the convention 1901-10 at year 1905 etc.) Although a rising trend appears in Figure 3 there is no sign of it in Figure 4.

The distribution of month-end values of psmd is shown in Figure 5. Each 2mm x 2mm square represents one case within a given range of psmd. In February and March all 106 values were below 49.99mm and hence 6 squares below the zero line are used.

3. An index of end-of-August psmd from 1698 to 1976.

The estimates of Penman pe from 1698 to 1869 ("pe") were made from temperature data only. The estimates from 1870 to 1875 were made from temperature and wind speed data. Sunshine duration and humidity data became available at Kew during 1876 (Wales-Smith, 1973). The series is probably as good as the data, Penman's formula and the approximation

thereto permit but it is not strictly homogeneous. To investigate variations of psmd (which includes pe) the pe estimates must be all of one kind over the whole period and hence must be "pe" based on temperature only. Annual and decadal totals of "pe", 1698-1976 are shown in Figure 6.

April to August(5 month) totals of "pe" are plotted in Figure 7 together with 10-year running means.
Corresponding rainfall (r) totals (Wales-Smith, 1977) and running means are also plotted. A coarse index of psmd A can be obtained by evaluating

$$\sum_{\text{Apr}}^{\text{Aug}} \text{"pe"} \quad - \quad \sum_{\text{Apr}}^{\text{Aug}} r \quad , \text{ assuming} \quad \text{---- (1)}$$

the soil to be at field capacity at the end of March.
A physically more realistic index("psmd A") is obtained by evaluating

$$(\text{"pe"}-r)_{\text{Apr}} + (\text{"pe"}-r)_{\text{May}} + (\text{"pe"}-r)_{\text{month } n} + (\text{"pe"}-r)_{\text{Jun}} + (\text{"pe"}-r)_{\text{Jul}} + (\text{"pe"}-r)_{\text{Aug}} \quad \text{--- (2)}$$

Appendix 3

with the restriction $\sum_{\text{Apr}} (\text{"pe"} - r)_{\text{month } n} \geq 0$ for all n from Apr to Aug.

"psmd A" estimates obtained in these two ways are compared in Figure 8.
It is seen that $(\text{"pe"}-r)_{\text{Apr}} + \ldots + (\text{"pe"}-r)_{\text{Aug}} \geq \sum_{\text{Apr}}^{\text{Aug}} \text{"pe"} - \sum_{\text{Apr}}^{\text{Aug}} r$

In Fig 9 "psmdA" obtained using Eq (2) is compared with rigorously calculated psmd A. The two sets of values are well correlated and in the vast majority of cases psmd A > "psmd A". The points are well fitted by the regression line (inserted by eye) psmdA = 1.11"psmd A". Of the 12 largest psmdA (and "psmdA") values those of 1976, 1921, 1959 and 1893 (in that order in both series) are clearly thetop 4. The 8 next largest values are very close to one another in size and also match very well between the two series.

4. Comments on the psmd A, $\sum_{\text{Apr}}^{\text{Aug}} \text{"pe"}$ and $\sum_{\text{Apr}}^{\text{Aug}} r$ series

Figure 6 shows that whilst there have been important oscillations in annual "pe" there has been no obvious long-period trend. At first sight the sustained rise from the decade beginning 1881 to that beginning 1941 is impressive but it can be seen that an equally large rise occurred from the decade beginning 1811 to that beginning 1841. The "pe" graph in Figure 7 is singularly unexciting. The r graph in Figure 7 shows oscillations but no obvious trend.
The graph of "psmd A" (in Figure 7) is roughly in anti-phase with the r graph. Interesting features of Figure 7 are:

(a) "psmd A" exceeded 10 ins (254mm) 17 times from 1856 to 1976 (121 years) but only 10 times from 1698 to 1855 (158 years) and

(b) April to August r was 7 ins (178 mm) or less 23 times from 1856 to 1976 (121 years) and only 19 times from 1698 to 1855 (158 years).
The rainfall totals for the period 1697 to 1855 (Wales-Smith, 1977) are estimates for Kew made, objectively, from falls recorded elsewhere. If these early measurements were in error they were generally too small (see, for example, Craddock and Wales-Smith, 1977). In preparing the revised series of monthly estimates for Kew for 1697 to 1855 (after which year good quality rainfall data became available for Kew) onjective allowances were made for under-catch by rain-gauges with shallow funnels, sited on roofs, too infrequently read (allowing loss by evaporation)etc. Very small over-estimates in this "correction" process could easily account for the slightly lower frequency of very low summer totals from 1697 to 1855 as compared with the period 1856 to 1976.

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Table 1. Estimated end-of-month Potential Soil Moisture Deficits at Kew Observatory

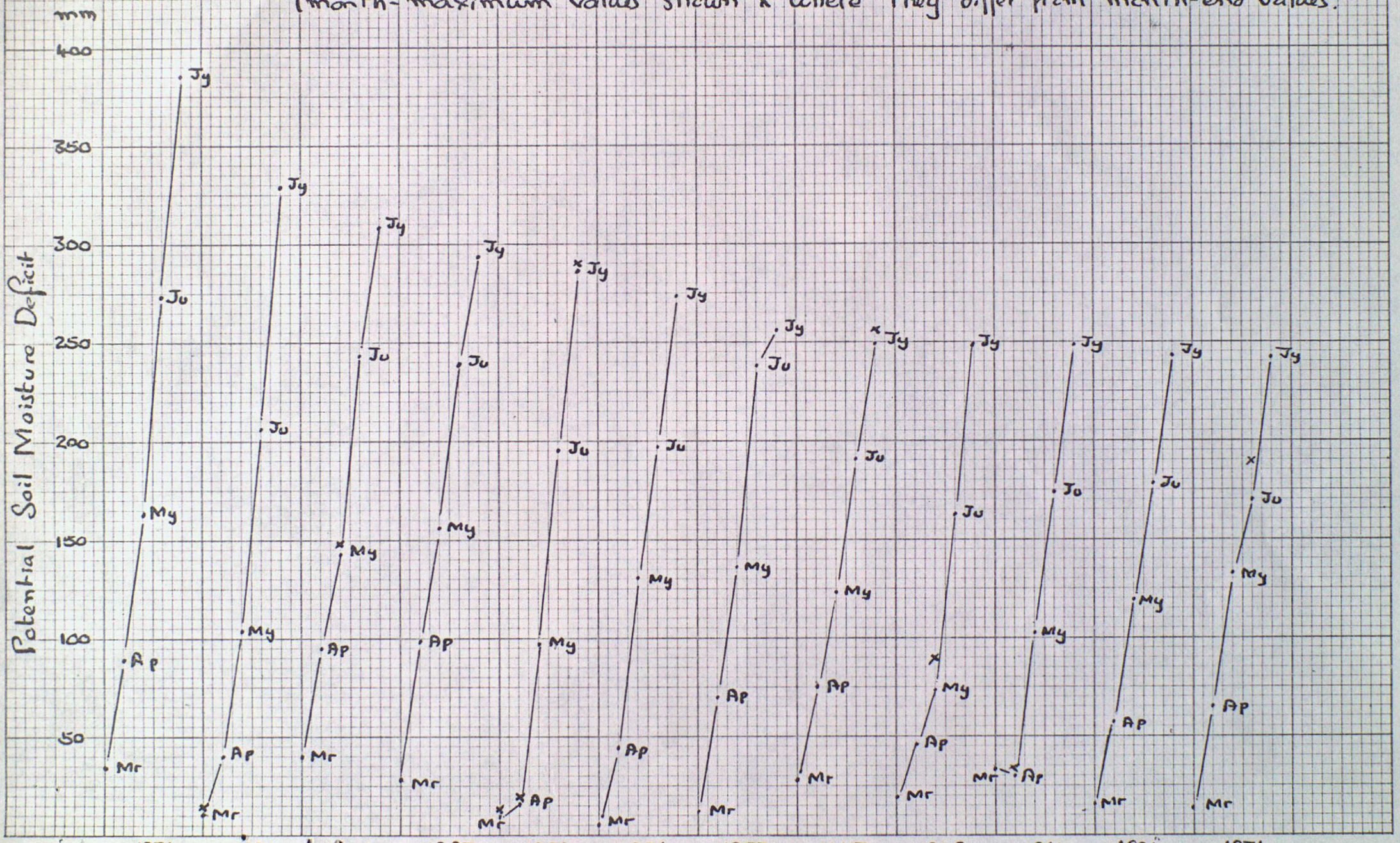
1871–1976 (mm) 12 highest values in each month May–Aug ranked (with year-dates)

RANK	MAY		JUNE		JULY		AUGUST		Cumulative Probability	Return period (years)
	mm	year	mm	year	mm	year	mm	year		
1	161·9	1976	272·8	1976	386·2	1976	470·9	1976	·9936	156
2	156·0	1893	243·5	1938	329·0	1921	387·9	1921	·9842	63
3	146·5	1956	239·4	1893	309·1	1938	356·5	1959	·9748	40
4	143·2	1938	237·8	1957	294·3	1893	345·8	1893	·9654	29
5	135·9	1957	207·0	1895	286·4	1959	321·0	1911	·9560	23
6	132·6	1974	206·0	1921	273·0	1896	319·4	1975	·9466	19
7	131·5	1896	196·5	1896	255·8	1957	317·3	1899	·9372	16
8	131·5	1944	195·5	1959	250·4	1943	316·5	1938	·9278	14
9	124·4	1943	193·3	1929	249·2	1949	315·7	1972	·9184	12
10	119·8	1881	191·3	1943	249·1	1961	308·8	1943	·9080	11
11	117·6	1929	189·7	1934	243·0	1881	301·2	1949	·8996	10
12	113·8	1934	189·0	1960	242·3	1974	297·2	1933	·8902	9

Notes :- 1. Pot SMD returned to zero with 3" (Penman) root constant SMD

2. Pot SMD set equal to 3" root constant SMD at end of February if no return to zero occurred for 3" root constant.

Fig. 1. Development of the 12 largest totals of end-of-July Potential Soil Moisture Deficit at Kew from 1871–1976 (month-maximum values shown x where they differ from month-end values.



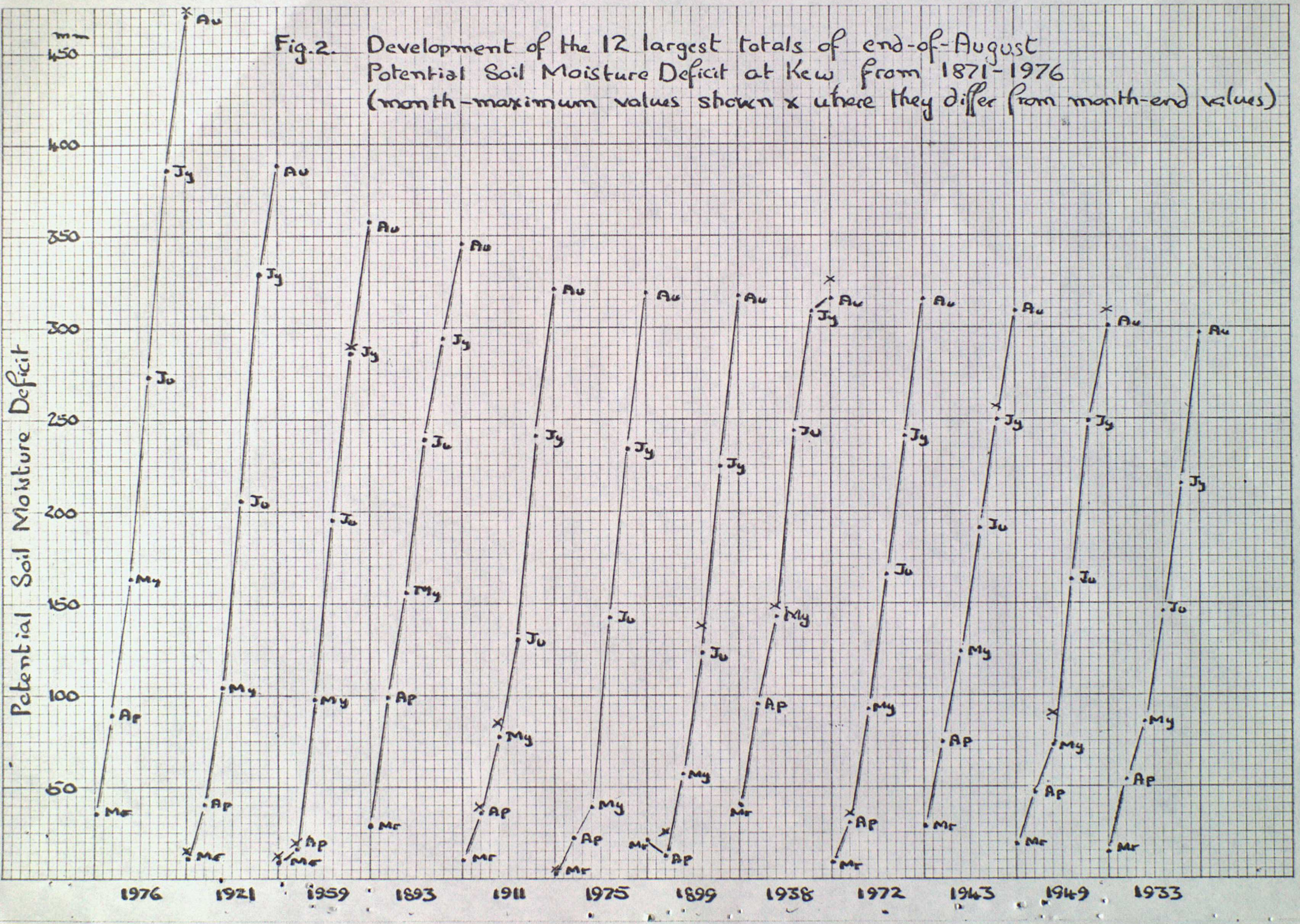


Fig.2. Development of the 12 largest totals of end-of-August Potential Soil Moisture Deficit at Kew from 1871-1976
(month-maximum values shown x where they differ from month-end values)
Potential Soil Moisture Deficit
mm
450
400
350
300
250
200
150
100
50
Mr
Ap
My
Jn
Jy
Au
1976
1921
1959
1893
1911
1975
1899
1938
1972
1943
1949
1933

Fig. 3. End-of-June Potential Soil Moisture Deficit – Kew – 1871 onwards mm.

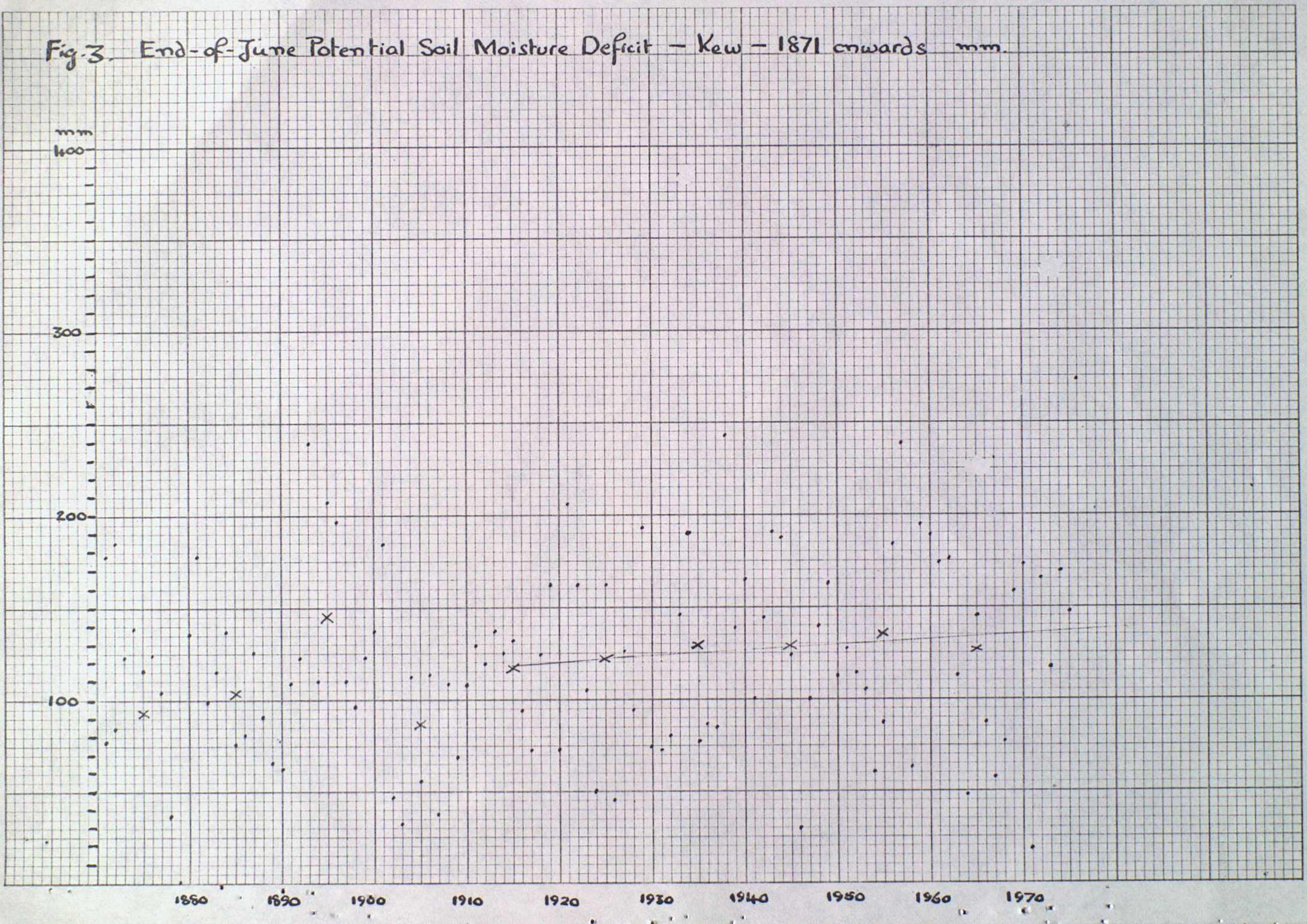
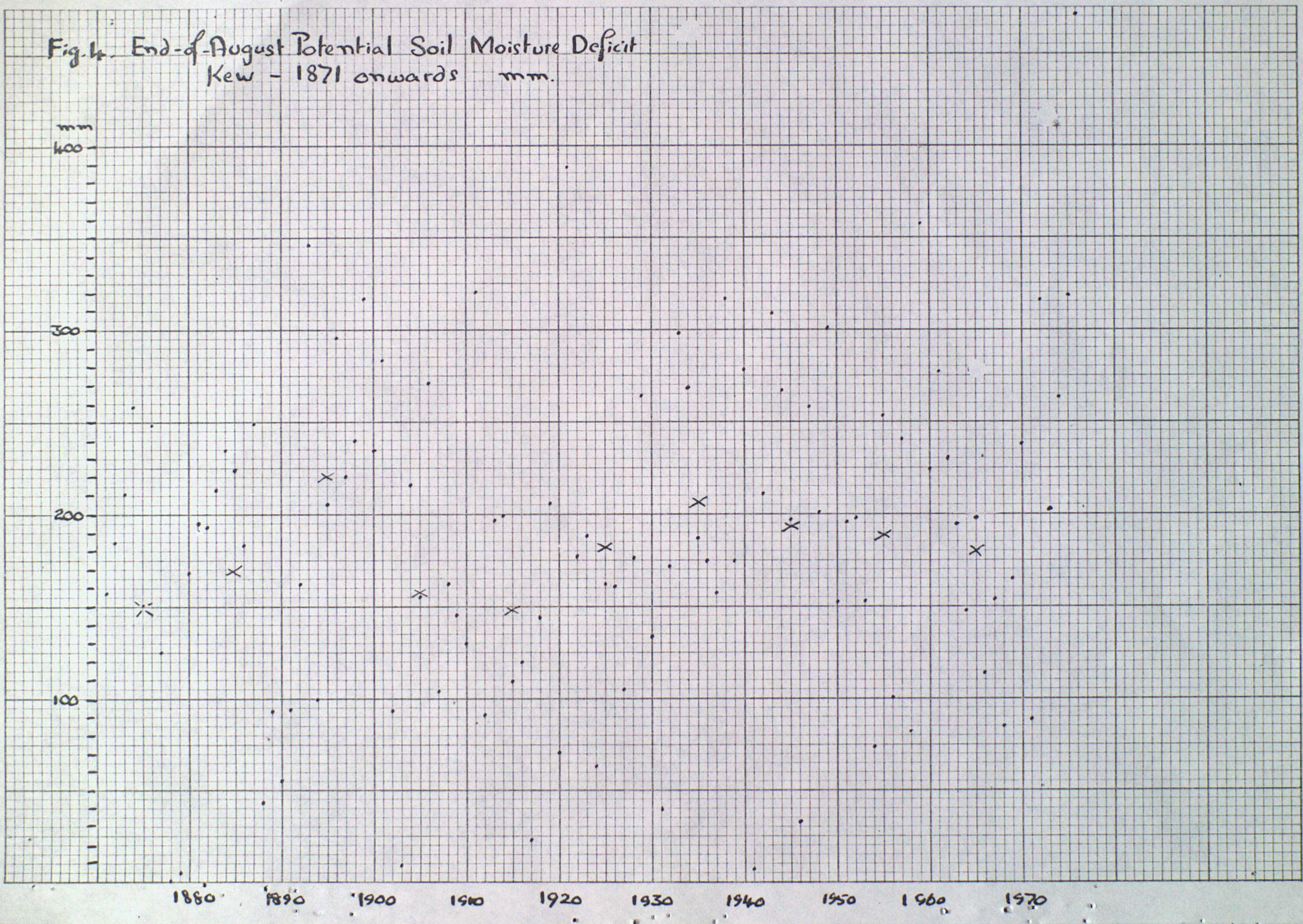


Fig. 4 End-of-August Potential Soil Moisture Deficit
Kew – 1871 onwards mm.



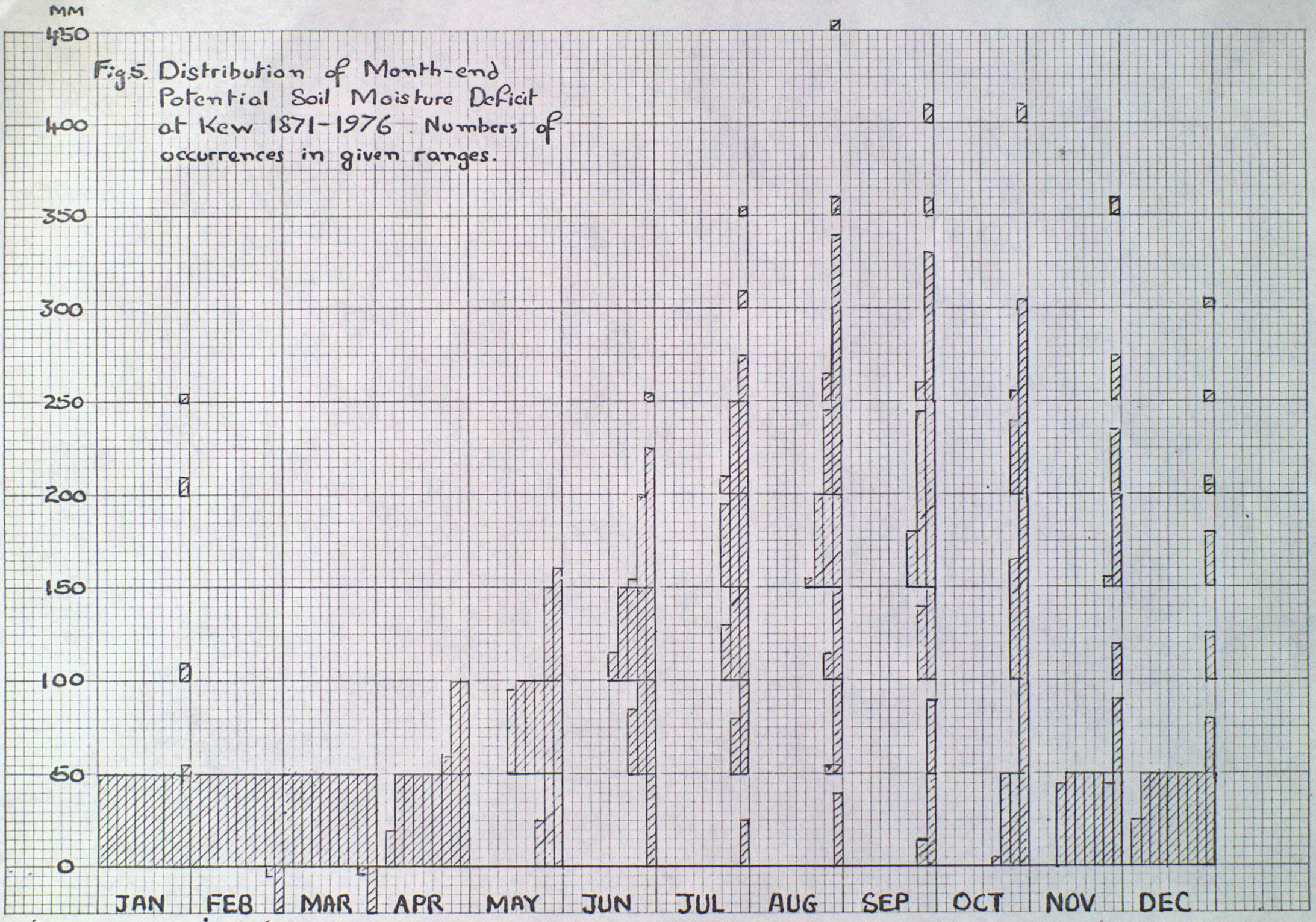


Fig 5. Distribution of Month-end Potential Soil Moisture Deficit at Kew 1871-1976. Numbers of occurrences in given ranges.

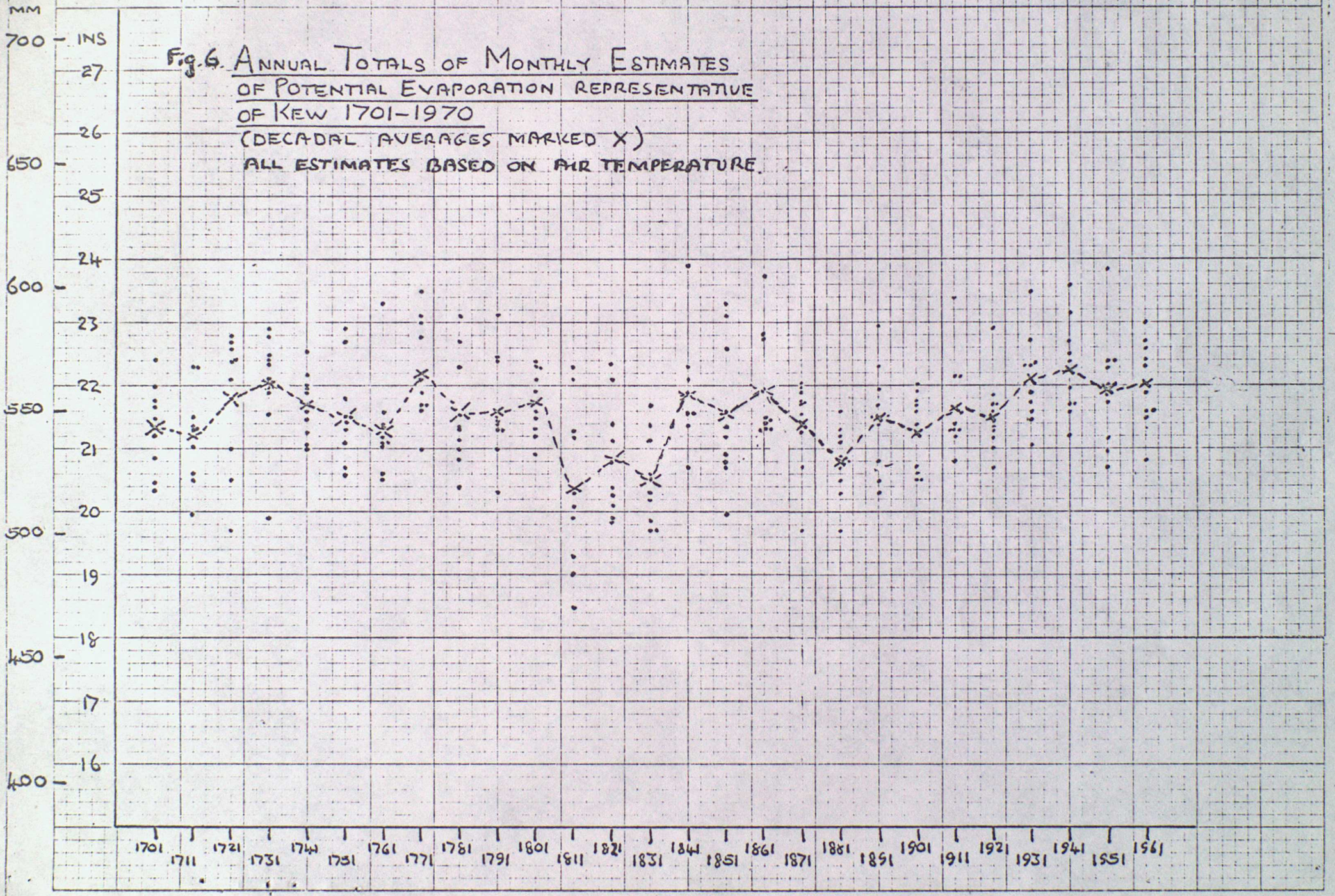


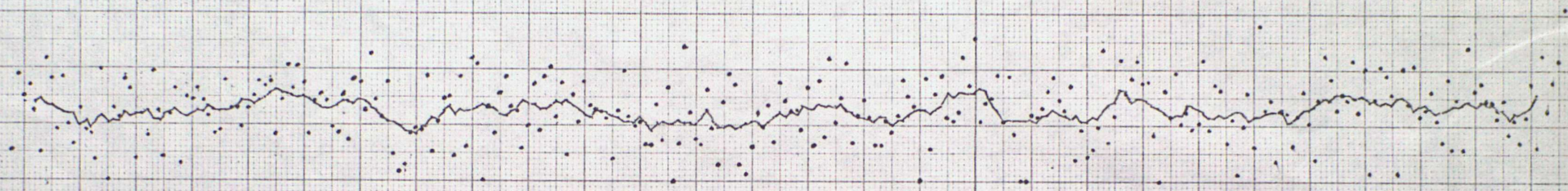
Fig. 6. ANNUAL TOTALS OF MONTHLY ESTIMATES OF POTENTIAL EVAPORATION REPRESENTATIVE OF KEW 1701–1970

(DECADAL AVERAGES MARKED X)

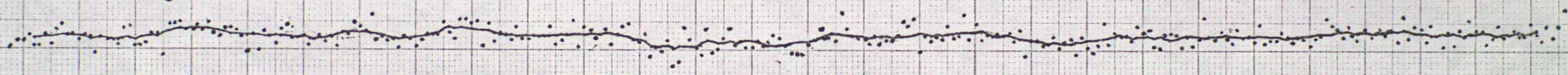
ALL ESTIMATES BASED ON AIR TEMPERATURE.

Kew 1697/8 - 1976 Annual totals and 10-year running means of April-August Approx PSMD and PE and of rainfall
(plotting convention 1701-1710 mean at year 1705 etc.)

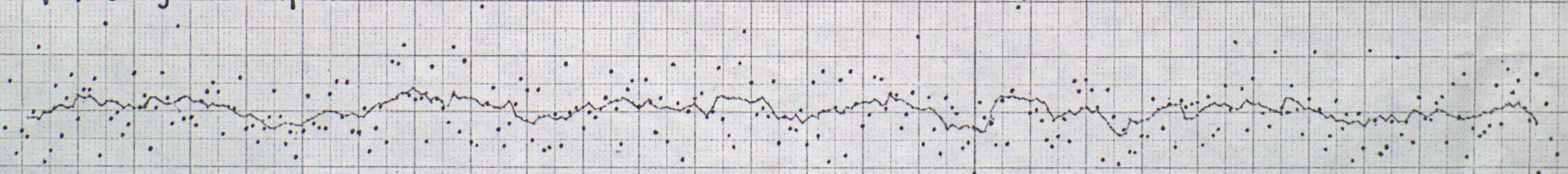
Approx
Potential SMD at end of August $(PE-R)_{Apr} + \cdots + (PE-R)_{Aug}$, for $(PE-R) \neq 0$



April to August approx Penman p.e.*



April to August Rainfall



1700 1710 1720 1730 1740 1750 1760 1770 1780 1790 1800 1810 1820 1830 1840 1850 1860 1870 1880 1890 1900 1910 1920 1930 1940 1950 1960 1970

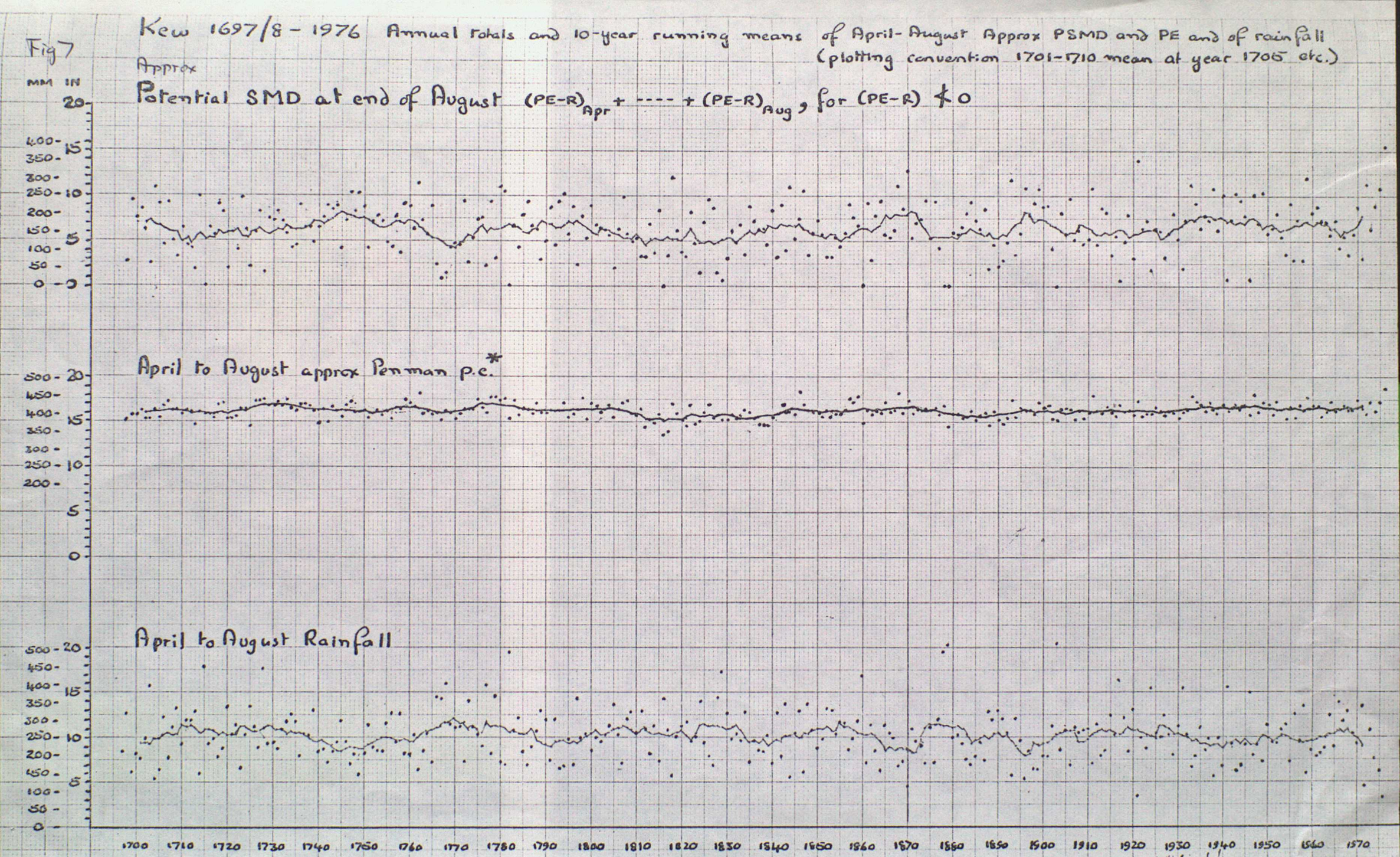
APR-AUG RAIN + POTENTIAL EVAPORATION + END-OF-AUGUST (APPROX) POTENTIAL SOIL MOISTURE DEFICIT
REPRESENTATIVE OF KEW, SURREY, 1698-1976

*PE= potential evaporation from [illegible]

Fig 7

Kew 1697/8 - 1976 Annual totals and 10-year running means of April-August Approx PSMD and PE and of rainfall
(plotting convention 1701-1710 mean at year 1705 etc.)

Approx
Potential SMD at end of August $(PE-R)_{Apr} + \cdots + (PE-R)_{Aug}$, for $(PE-R) \neq 0$



APR-AUG RAIN + POTENTIAL EVAPORATION + END-OF-AUGUST (APPROX) POTENTIAL SOIL MOISTURE DEFICIT
REPRESENTATIVE OF KEW, SURREY, 1698-1976

*PE = potential evaporation from [illegible]

Fig. 8. Comparison of two measures of end-of-August potential soil moisture deficit at Kew 1698–1976 (184 values coincided and are not plotted)

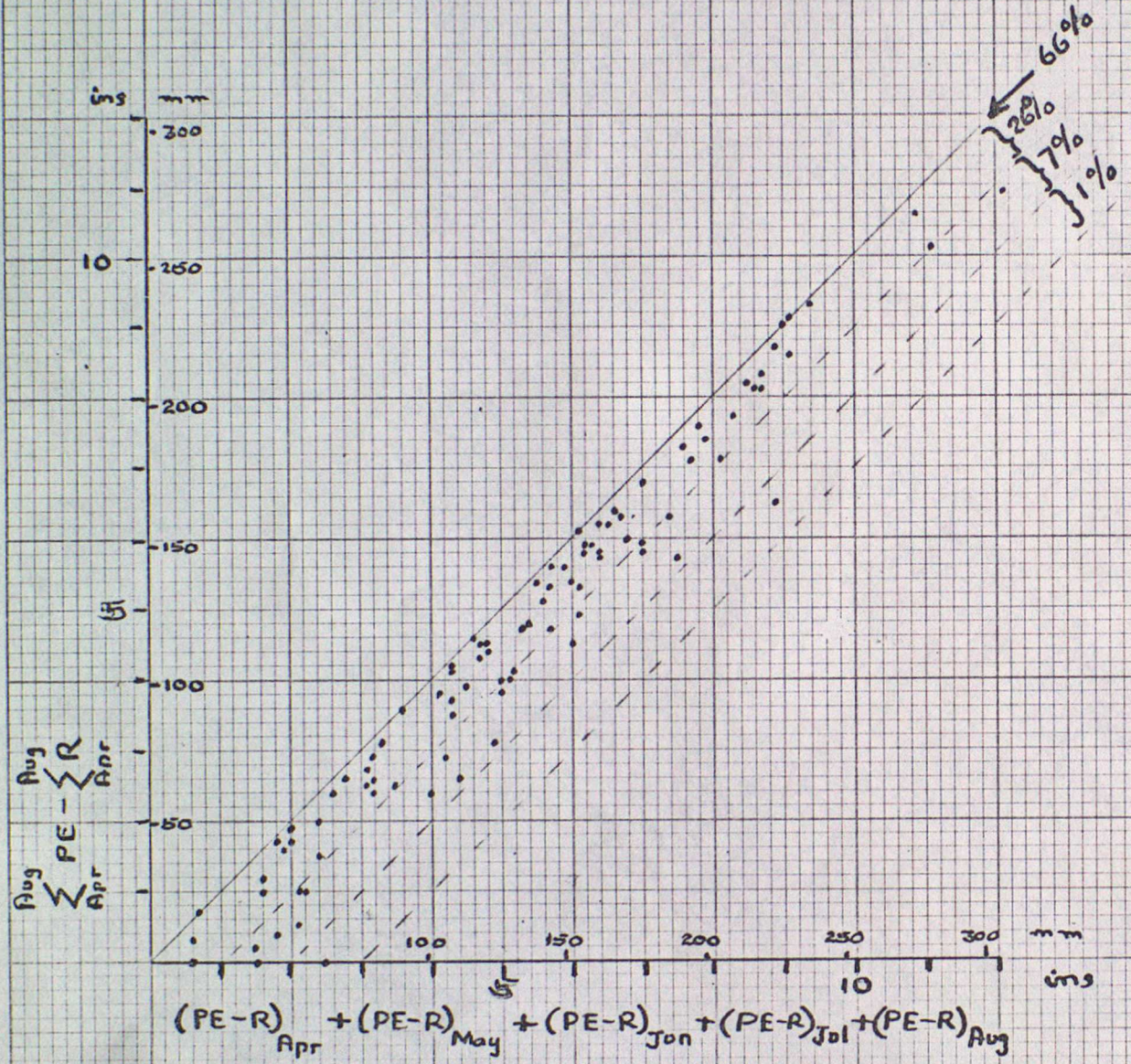
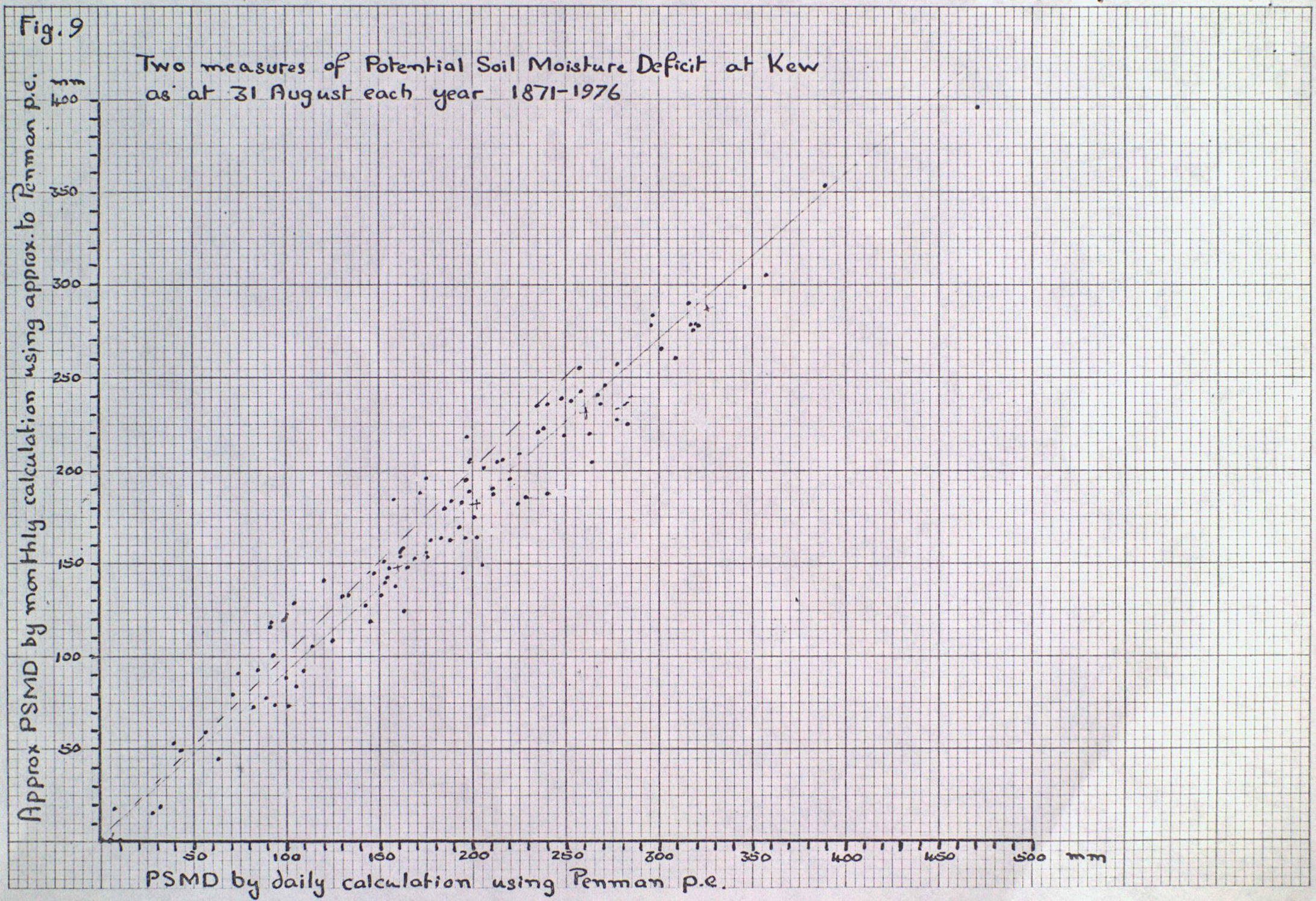


Fig. 9

Two measures of Potential Soil Moisture Deficit at Kew
as at 31 August each year 1871–1976



Appendix 1.

Month-end Potential Soil Moisture Deficit (mm) Kew Observatory

	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	
January	0·8	1·7	2·8	2·6	0·6	0·0	0·0	0·8	4·4	0·8	
February	5·5	2·0	1·2	1·1	1·5	0·0	2·5	0·0	0·0	1·9	
March	21·9	5·1	10·8	25·8	24·3	7·7	2·5	10·8	5·5	25·1	
April	8·3	22·0	52·3	52·8	30·8	9·1	12·8	10·5	6·8	30·8	
May	64·6	25·2	96·5	110·2	81·6	64·7	35·4	8·0	1·0	107·6	
June	76·8	84·8	122·5	139·2	115·9	123·9	103·6	26·7	0·9	135·8	93·0
July	95·3	142·0	174·1	213·2	84·4	211·3	114·0	60·7	14·2	105·6	
August	156·5	155·0	210·5	257·6	150·9	247·8	124·7	0·8	4·9	168·4	150·7
September	109·6	200·1	195·0	230·6	152·1	225·6	146·4	18·1	0·0	103·4	
October	101·6	109·4	139·7	162·3	76·8	244·6	117·8	0·0	1·0	0·7	
November	95·8	0·0	0·1	0·1	1·0	150·6	0·0	0·0	0·5	0·4	
December	69·1	0·0	0·0	1·2	0·0	0·0	0·0	0·0	0·0	0·2	

	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890	
January	0·0	0·4	0·5	0·0	127·4	0·0	0·1	0·0	0·0	0·0	
February	2·2	0·0	1·6	4·5	0·4	3·7	5·3	9·3	1·4	7·0	
March	16·3	10·8	8·5	21·7	10·4	1·3	0·0	1·5	6·1	8·2	
April	56·7	3·8	21·6	35·2	24·1	24·4	25·8	13·4	4·5	17·9	
May	119·8	67·1	55·0	108·8	25·9	6·5	51·4	71·6	5·1	66·8	
June	177·8	99·0	116·4	137·2	76·3	81·2	126·4	91·1	66·4	61·8	103·3
July	243·0	143·1	154·7	170·1	174·2	120·1	225·4	45·4	74·6	30·9	
August	195·4	193·1	213·3	235·4	224·0	183·1	248·7	43·2	92·5	56·0	168·5
September	177·8	177·6	176·7	239·8	157·6	198·7	239·5	47·3	97·0	90·3	
October	139·3	0·4	152·8	232·3	0·0	154·3	222·6	30·6	11·7	86·7	
November	0·0	0·2	0·0	195·9	0·0	86·6	152·0	0·0	0·3	54·9	
December	0·0	0·0	0·4	155·2	0·0	0·0	0·4	0·1	0·0	52·0	

	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	
January	13·7	0·0	0·0	0·0	0·0	1·2	0·0	136·4	0·9	0·4	
February	19·8	1·9	0·0	0·0	15·9	5·7	3·2	(1·2)	8·0	0·5	
March	22·1	6·5	29·3	20·5	15·2	5·1	1·0	8·7	21·4	8·7	
April	47·8	41·5	99·2	39·7	26·4	43·8	20·3	35·8	12·6	40·4	
May	57·1	92·6	156·0	77·9	107·8	131·5	81·3	44·2	57·3	91·5	
June	109·1	121·7	239·4	110·3	207·0	196·5	110·2	96·4	122·7	136·5	145·0
July	127·3	165·3	294·3	91·5	194·1	273·0	197·7	177·5	224·9	226·5	
August	93·6	161·6	345·8	100·0	205·2	295·6	220·4	239·9	317·3	234·9	221·4
September	114·5	124·7	371·7	106·5	219·6	208·5	213·5	288·5	317·4	268·4	
October	1·7	0·1	288·5	27·8	159·3	2·2	219·1	226·5	285·4	247·3	
November	0·0	0·1	250·7	0·7	0·2	1·9	204·2	179·0	2·8	211·8	
December	0·0	1·2	0·0	0·2	0·4	0·0	154·3	0·0	0·0	152·6	

M-E PSMO Kew

	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910	
January	0·8	1·4	0·0	0·0	1·6	0·9	2·9	1·8	1·3	0·8	
February	0·0	0·0	0·0	4·9	1·0	0·7	4·8	0·8	8·9	0·0	
March	1·4	1·8	2·0	3·8	8·7	7·3	17·5	1·4	0·9	19·5	
April	32·6	43·0	8·0	38·6	19·9	53·9	0·0	2·2	21·1	43·8	
May	110·6	52·9	9·0	37·0	93·0	93·5	31·3	51·3	83·6	85·1	
June	183·7	47·4	32·0	111·6	56·2	113·5	37·4	108·4	69·2	108·5	86·8
July	239·7	115·3	17·0	177·2	146·3	192·2	80·5	142·5	96·5	125·3	
August	282·6	93·3	9·6	216·2	155·2	271·4	104·2	161·6	145·4	130·2	157·0
September	291·3	77·8	1·0	225·6	156·9	279·2	132·8	169·2	121·0	165·5	
October	263·3	65·6	0·0	204·0	142·3	212·7	58·4	135·4	55·3	126·2	
November	260·3	34·2	0·0	164·8	70·9	0·0	0·3	125·6	43·4	61·1	
December	179·2	0·3	1·9	118·5	0·2	0·0	1·9	78·8	0·0	1·4	

	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	
January	2·4	2·4	0·3	1·7	2·1	1·7	5·9	0·3	0·4	0·0	
February	0·0	2·2	10·8	3·2	0·6	0·0	1·9	1·9	0·6	3·9	
March	10·6	1·4	2·4	4·0	14·7	3·3	0·6	13·4	2·1	12·9	
April	35·4	64·8	0·2	45·4	37·1	35·7	21·6	13·3	2·7	7·9	
May	76·8	112·2	51·3	80·4	48·3	71·2	60·3	57·3	90·4	56·5	
June	128·5	119·9	136·9	125·2	132·1	94·3	71·7	124·9	162·3	72·2	116·8
July	240·7	165·5	162·8	166·6	121·1	142·8	53·9	100·9	170·1	42·2	
August	321·0	91·2	196·7	198·8	108·6	119·9	27·9	143·0	206·3	70·9	148·4
September	343·3	81·5	196·7	226·4	98·6	120·9	23·7	146·9	222·7	55·4	
October	289·9	0·0	127·0	218·0	61·2	0·0	0·4	1·5	225·2	32·1	
November	1·2	0·2	0·0	150·5	0·0	0·1	0·7	0·0	205·7	2·3	
December	0·8	0·5	1·3	0·0	0·0	0·0	0·0	0·2	116·2	0·0	

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930	
January	0·0	293·6	0·4	0·5	0·0	0·0	0·0	0·0	0·0	0·0	
February	8·6	0·0	0·0	6·3	0·2	2·5	0·0	6·3	4·7	11·2	
March	10·8	16·1	2·2	15·3	18·8	34·4	0·0	1·4	31·2	14·2	
April	41·1	9·1	14·8	0·0	18·3	12·1	39·7	20·6	56·9	21·9	
May	104·4	82·4	25·2	20·5	52·4	43·5	104·1	51·8	117·6	5·4	
June	206·0	162·3	105·2	49·6	161·6	45·5	126·1	94·3	193·3	75·1	121·9
July	329·0	163·9	134·9	67·9	159·0	94·4	133·7	159·4	241·5	121·8	
August	387·9	176·7	187·8	62·9	162·3	160·9	105·5	176·4	264·2	133·5	181·8
September	395·4	177·9	199·8	35·6	139·6	169·4	0·8	197·5	317·1	113·1	
October	404·7	180·6	0·0	0·0	1·8	138·1	0·0	126·5	269·0	108·4	
November	369·1	151·5	0·1	0·0	0·0	0·0	0·1	91·5	0·0	0·0	
December	345·5	85·4	0·0	0·0	0·0	1·8	0·0	0·0	0·1	0·0	

M-E PSMD Kew

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940	
January	0·0	2·1	0·0	2340	0·3	0·0	0·0	0·0	1·0	0·0	
February	0·0	14·1	1·2	(43·3)	0·2	0·0	0·0	10·3	0·0	0·3	
March	30·4	12·2	15·2	(17·9)	24·1	4·1	7·8	40·2	12·1	5·6	
April	7·1	11·7	53·5	(32·6)	13·2	15·9	13·9	95·1	18·7	17·0	
May	20·7	4·6	86·4	(112·8)	64·6	88·2	35·6	143·2	64·0	77·6	
June	71·8	81·0	146·3	(189·7)	77·5	88·9	85·2	243·5	139·3	164·6	128·6
July	87·4	118·5	215·2	(232·4)	155·4	112·3	149·2	309·1	188·2	192·2	
August	39·3	172·2	297·2	(267·9)	188·6	176·0	157·0	316·5	175·2	277·7	205·5
September	23·7	154·9	287·2	(288·6)	172·6	145·4	149·2	312·1	204·0	295·6	
October	24·5	0·8	274·2	(287·7)	142·5	123·5	110·2	281·3	100·1	255·5	
November	0·1	0·0	257·9	(248·9)	0·0	0·1	78·3	223·8	0·0	0·6	
December	0·4	0·0	260·6	0·0	0·0	0·0	0·0	0·0	0·1	0·0	

	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950	
January	0·0	0·0	0·0	2·4	0·0	0·0	0·0	0·0	1·7	0·0	
February	0·0	13·5	6·2	9·3	7·4	1·7	8·3	6·4	1·6	2·7	
March	1·6	8·2	29·4	38·4	21·8	10·5	0·5	25·7	18·7	19·8	
April	26·8	62·7	75·3	61·1	53·1	22·5	32·5	58·9	47·3	14·0	
May	52·1	74·7	124·4	131·5	70·7	14·9	81·6	92·3	72·5	49·9	
June	100·7	144·4	191·3	187·3	124·3	29·6	101·3	140·0	163·3	112·3	129·5
July	105·4	194·3	250·4	231·2	156·3	54·6	159·1	203·4	249·2	131·8	
August	6·7	211·2	308·8	267·4	196·8	31·8	256·9	200·5	301·2	152·2	193·3
September	38·8	230·7	297·8	256·1	196·3	9·4	280·7	216·7	348·6	129·6	
October	41·0	164·4	251·7	210·5	163·5	0·0	299·3	187·9	233·6	139·8	
November	0·3	0·9	226·6	0·3	164·0	0·0	280·6	149·1	0·1	0·0	
December	0·5	0·0	195·5	0·0	97·9	0·0	230·7	0·0	0·4	0·0	

	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	
January	0·8	0·0	0·1	2·4	1·7	0·0	0·0	0·8	0·5	0·7	
February	0·9	5·0	6·2	0·0	2·4	8·5	2·2	1·8	9·0	1·8	
March	2·7	1·4	22·0	0·0	14·2	26·0	11·7	6·2	9·1	10·7	
April	24·6	24·9	16·5	50·2	64·8	55·4	70·1	48·6	16·0	60·9	
May	46·8	54·0	71·7	79·6	52·9	146·5	135·9	79·7	97·2	104·9	
June	126·9	113·7	104·9	60·5	87·3	184·1	237·8	63·2	195·5	189·0	136·3
July	204·4	206·7	109·1	87·7	185·9	124·2	255·8	98·6	286·4	195·9	
August	195·8	197·8	153·3	73·8	252·8	101·1	239·8	81·8	356·5	224·5	187·7
September	185·2	169·9	152·5	81·2	256·3	90·9	227·0	30·4	422·5	185·7	
October	181·5	123·3	101·1	57·0	214·2	5·9	202·6	0·0	405·1	0·0	
November	0·0	0·2	78·5	0·0	199·6	4·9	2·3	1·2	351·0	0·3	
December	0·0	0·0	66·5	3·0	157·4	0·0	0·7	0·0	0·0	0·1	

M-E PSMO Kew.

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	
January	0·0	0·0	0·0	0·0	99·8	0·0	0·5	2·8	0·9	0·1	
February	0·0	13·3	7·5	0·0	(29·3)	2·0	0·9	8·7	3·3	3·4	
March	33·0	11·0	1·7	9·6	(16·7)	30·3	23·7	29·6	9·6	7·1	
April	29·9	31·0	8·3	5·3	(38·5)	10·4	32·0	29·8	59·2	7·3	
May	101·6	72·9	56·7	55·7	(91·9)	50·9	10·9	37·0	78·9	79·1	
June	173·8	176·4	112·2	47·9	(144·7)	87·0	56·7	77·5	157·6	173·0	120·7
July	249·1	208·0	177·6	105·8	(176·1)	111·2	114·0	94·7	185·0	209·0	
August	276·5	229·4	193·8	147·6	(187·8)	114·2	153·6	84·8	164·9	238·2	180·1
September	265·7	206·2	183·8	195·7	(134·7)	137·2	141·1	8·9	204·4	234·0	
October	242·2	174·2	168·1	184·5	(137·2)	56·3	77·7	0·0	221·6	248·2	
November	203·3	131·5	0·2	162·6	0·0	0·3	0·0	0·0	149·3	0·0	
December	0·0	0·0	0·0	137·5	0·0	0·3	0·0	0·2	113·2	0·3	

	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980
January	0·0	1·1	231·8	0·0	0·0	7·3				
February	4·8	5·0	(17·7)	4·5	5·9	6·9				
March	14·8	9·2	(38·2)	14·3	2·4	35·8				
April	32·0	30·6	(48·3)	65·4	22·2	88·8				
May	53·4	91·9	(71·4)	132·6	38·8	161·9				
June	17·7	165·7	(116·5)	169·7	141·6	272·8				
July	98·5	241·1	(156·9)	242·3	233·6	386·2				
August	88·6	315·7	(202·3)	262·7	319·4	470·9				
September	120·2	334·6	(185·9)	186·7	249·7	409·2				
October	88·7	344·5	(182·3)	3·5	248·4	0·0				
November	25·8	294·8	(158·4)	0·2	0·2	0·0				
December	0·4	237·6	(122·6)	1·5	0·0	0·0				

	1	1	1	1	1	1	1	1	1	1
January										
February										
March										
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May										
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July										
August										
September										
October										
November										
December										

Appendix 2.

Month-maximum Potential Soil Moisture Deficit (mm) Kew Observatory.

	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880
January	0·8	69·1	2·8	2·6	0·6	0·0	0·0	0·8	4·4	0·8
February	5·5	2·0	1·2	1·1	1·5	0·0	2·5	2·3	4·4	1·9
March	21·9	12·8	11·6	25·8	24·3	12·1	2·5	23·9	13·7	30·6
April	36·3	22·0	52·3	62·8	30·8	19·4	12·8	15·9	6·8	30·8
May	64·6	27·7	96·5	110·2	81·6	64·7	36·7	20·5	27·7	109·9
June	92·8	85·5	136·1	161·0	121·3	123·9	103·6	31·4	8·5	135·8
July	100·8	142·0	174·1	214·6	128·4	211·3	114·0	86·8	16·6	135·8
August	156·5	185·0	216·1	257·6	150·9	255·8	143·0	66·1	27·1	168·4
September	169·9	213·7	210·5	259·9	181·3	247·8	146·4	18·1	19·2	184·2
October	109·6	200·1	195·0	230·6	152·1	225·6	152·9	22·0	8·0	104·2
November	101·6	109·4	139·7	162·3	76·8	244·6	118·0	2·0	2·6	2·7
December	95·8	0·0	0·1	1·2	1·0	150·6	0·0	0·0	0·7	2·0

	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890
January	1·2	0·4	0·5	0·6	155·2	0·0	0·1	0·4	0·0	0·0
February	2·2	0·0	3·0	4·5	127·4	5·3	6·0	9·3	1·5	7·0
March	16·3	15·7	9·1	21·7	10·4	13·3	11·2	13·6	8·2	8·2
April	56·7	33·4	35·3	35·5	25·7	25·2	34·8	13·4	12·4	24·5
May	119·8	67·1	55·0	108·8	26·5	45·7	51·4	71·6	5·1	66·8
June	177·8	99·0	116·4	137·2	76·3	81·2	126·4	105·9	66·4	90·9
July	248·7	143·1	154·7	170·1	174·2	120·1	225·4	92·7	89·7	65·4
August	256·7	198·7	223·5	243·4	224·0	183·1	273·5	69·2	92·5	59·2
September	196·4	199·8	213·9	241·8	225·9	195·5	248·7	61·3	118·8	90·3
October	177·8	178·3	176·9	245·2	159·2	189·9	246·7	56·4	97·0	95·7
November	139·3	0·4	153·0	232·3	0·0	164·3	222·6	30·6	12·1	86·7
December	0·0	0·2	1·2	195·9	0·0	86·6	152·3	0·1	0·3	57·7

	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
January	52·2	0·0	0·0	0·0	0·9	1·2	0·0	154·3	0·9	0·4
February	19·8	2·1	0·0	0·0	15·9	5·7	4·1	136·9	8·0	0·5
March	24·9	6·5	29·3	20·5	24·3	5·9	9·0	120·0	22·0	8·7
April	47·8	41·5	99·2	47·2	38·1	43·8	25·2	37·1	26·1	40·4
May	57·1	98·9	156·0	82·3	107·8	131·5	86·8	49·0	57·3	91·5
June	109·9	141·1	239·4	110·3	207·0	196·5	119·2	98·0	138·0	136·5
July	137·9	165·3	294·3	127·1	247·9	273·8	197·7	177·5	224·9	226·5
August	140·0	202·9	314·1	110·9	216·4	306·7	239·0	239·9	317·5	242·1
September	115·6	179·0	375·9	114·4	219·6	295·6	220·4	291·6	340·1	275·5
October	114·5	124·7	372·7	109·5	219·6	209·9	219·1	296·5	321·5	271·6
November	3·3	0·1	288·5	27·8	160·3	2·2	221·5	226·8	285·4	247·3
December	0·0	1·5	250·7	0·9	0·4	1·9	204·2	179·0	2·8	211·8

M-M PSMO Kew

	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910
January	0·8	1·4	0·3	0·0	116·5	0·9	3·5	3·4	79·0	0·8
February	1·6	1·5	0·0	4·9	5·6	1·2	4·8	6·7	11·6	0·8
March	1·4	2·1	2·0	14·6	8·7	7·3	17·5	1·4	9·2	19·5
April	32·6	43·0	32·5	38·6	23·6	54·0	22·1	2·2	28·0	44·1
May	110·6	52·9	34·6	59·8	94·5	93·5	32·9	51·4	88·5	85·1
June	197·9	54·4	32·0	111·6	100·6	168·6	54·8	108·4	96·6	124·8
July	258·0	115·3	80·2	191·4	146·3	200·4	80·5	142·5	110·6	125·3
August	300·3	119·6	32·9	237·8	179·0	271·4	104·2	192·0	146·4	131·5
September	303·4	108·1	15·9	228·0	171·5	279·2	135·0	169·2	149·5	165·5
October	291·3	84·4	1·1	225·6	166·9	279·2	132·8	176·2	122·2	174·5
November	262·6	66·6	0·0	206·5	142·3	212·7	60·7	138·6	57·3	127·0
December	260·3	34·2	1·9	164·9	71·3	0·2	1·9	126·2	43·4	61·1

	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
January	2·4	2·4	0·6	1·9	2·1	1·7	5·9	0·5	0·4	116·2
February	4·5	3·7	10·8	3·3	2·1	2·0	6·8	1·9	0·6	3·9
March	10·6	9·0	15·5	4·0	14·7	3·3	3·2	23·6	2·1	12·9
April	38·7	64·8	8·9	45·4	37·1	35·7	21·6	15·4	2·7	12·9
May	85·2	119·2	68·8	83·8	64·7	71·2	62·1	57·3	90·4	63·2
June	130·9	119·9	136·9	125·2	132·1	96·3	110·0	124·9	162·3	87·3
July	240·7	168·7	162·8	166·6	147·7	142·8	109·6	150·4	170·1	73·5
August	321·0	169·2	212·9	198·8	121·1	175·1	53·9	143·0	236·2	70·9
September	347·1	128·2	196·7	226·4	143·3	121·4	35·1	149·1	220·7	93·1
October	347·5	81·5	212·9	237·2	110·0	120·9	25·1	149·7	230·6	55·4
November	290·6	1·7	127·0	218·0	61·2	0·1	0·7	1·5	225·2	32·1
December	1·4	0·6	1·3	150·5	0·0	0·4	1·2	0·2	205·7	2·4

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
January	0·0	346·0	85·4	0·5	0·0	0·0	0·0	0·0	0·0	0·0
February	10·2	293·9	0·5	8·2	0·2	2·5	0·0	7·6	4·7	11·2
March	15·1	18·2	2·2	15·3	18·8	34·4	0·6	11·3	31·2	14·2
April	41·1	18·6	17·2	25·5	25·0	40·7	39·7	21·0	59·5	21·9
May	104·4	82·4	41·6	25·6	53·1	43·5	104·1	51·8	117·6	25·8
June	206·0	163·5	105·2	49·6	161·6	45·5	148·5	94·3	193·3	75·1
July	329·0	166·7	140·3	98·8	210·7	96·6	133·7	169·6	250·3	122·7
August	387·9	183·3	192·2	73·7	183·2	161·2	143·1	181·3	264·2	143·0
September	408·9	193·5	205·8	73·3	168·8	174·8	116·2	200·3	318·3	141·0
October	404·7	180·5	200·2	39·4	149·3	176·4	0·8	204·1	317·1	120·0
November	405·1	180·6	0·1	0·0	1·8	138·6	0·1	130·9	270·4	108·4
December	369·1	151·5	0·1	0·0	0·0	1·8	2·2	91·5	0·1	0·0

MM PSMD Kew

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
January	0.0	2.1	0.0	260.6	0.5	0.0	0.0	0.0	1.0	0.6
February	0.0	14.1	1.2	241.6	0.3	0.0	0.0	12.1	4.2	0.5
March	30.4	26.5	15.2	(44.0)	24.1	10.4	7.8	40.2	12.1	6.6
April	30.4	12.0	53.5	(36.8)	25.8	21.3	13.9	95.1	33.0	24.3
May	30.9	11.7	85.4	(112.8)	64.6	86.2	35.6	148.9	64.0	77.6
June	71.8	94.5	146.3	(189.7)	77.5	93.8	85.2	243.5	139.3	164.6
July	108.4	128.0	215.2	(244.7)	155.4	112.7	149.2	309.1	188.2	192.2
August	93.0	172.2	298.1	(281.9)	211.4	175.0	182.4	326.0	188.2	277.7
September	40.9	179.6	322.3	(290.3)	194.9	180.0	165.4	340.4	204.0	299.5
October	29.8	155.9	292.3	(268.9)	173.6	161.4	162.5	312.5	207.0	296.6
November	25.1	3.3	274.2	(258.4)	142.5	123.5	110.2	284.5	100.6	255.9
December	0.4	0.0	264.2	(248.9)	0.0	0.1	78.3	223.8	0.1	1.0

	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
January	0.0	0.9	0.0	195.9	0.0	97.9	0.0	230.7	1.8	0.5
February	0.0	13.5	6.2	9.3	7.4	1.7	8.3	6.4	3.3	2.7
March	2.4	14.6	29.4	38.4	28.1	10.5	9.8	33.7	18.7	19.8
April	26.8	62.7	75.3	61.1	63.3	46.7	32.5	58.9	48.8	34.9
May	65.8	85.5	124.4	131.5	76.4	34.8	81.6	101.5	89.8	49.9
June	100.7	172.3	191.3	189.4	124.3	29.6	124.4	140.0	163.3	112.3
July	139.7	194.3	256.9	231.2	156.3	94.5	159.1	206.6	249.2	131.8
August	113.4	220.0	308.8	282.9	196.8	70.8	256.9	206.1	308.5	172.4
September	144.3	240.3	319.9	267.4	199.7	32.7	287.2	216.7	348.6	155.6
October	145.8	234.5	301.4	262.7	210.7	10.5	299.3	223.8	354.2	142.2
November	142.0	1.9	251.7	212.1	168.1	0.0	300.3	187.9	234.4	139.8
December	0.7	0.9	226.6	0.3	164.0	0.0	281.2	149.2	0.4	0.0

	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
January	0.8	0.0	0.1	66.5	3.3	157.4	0.0	0.8	0.6	0.7
February	0.9	5.0	6.2	3.4	2.4	8.5	2.2	1.8	9.0	1.8
March	2.7	6.2	26.2	0.0	17.8	26.0	12.6	17.5	11.7	18.0
April	27.9	25.7	35.4	50.2	64.8	56.4	70.1	48.6	18.7	60.9
May	49.6	54.0	71.7	83.3	78.7	146.5	135.9	100.9	97.2	104.9
June	126.9	113.7	105.3	90.2	87.3	184.8	237.8	68.2	195.5	189.0
July	204.4	206.7	128.9	100.0	185.9	189.0	255.8	96.6	288.8	203.7
August	216.1	212.6	163.7	97.7	252.8	130.0	277.2	117.8	356.5	224.5
September	203.8	221.3	177.7	82.5	264.9	101.1	250.8	86.1	422.5	224.5
October	196.3	222.4	160.2	89.0	258.1	90.9	239.0	30.4	434.2	185.7
November	181.5	118.6	101.1	57.8	214.7	9.2	202.6	2.0	405.4	0.3
December	0.0	0.2	78.5	3.0	201.0	6.4	2.6	1.2	351.4	0.3

M-M PSMD Kew

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
January	0·1	0·0	0·0	0·0	139·0	0·0	0·5	2·8	0·9	113·2
February	0·0	13·3	7·5	0·0	106·7	2·0	0·9	8·7	3·3	3·4
March	33·0	24·8	13·5	9·6	(34·1)	30·3	23·7	29·6	10·6	9·3
April	33·0	31·0	16·9	9·6	(44·0)	31·5	32·0	47·2	59·2	8·0
May	101·6	72·9	56·7	65·3	(94·4)	50·9	35·6	37·0	78·9	79·1
June	173·8	176·4	120·0	65·3	(147·2)	94·1	77·7	80·3	157·6	175·8
July	249·1	229·9	177·6	105·8	(178·6)	132·6	127·7	98·6	209·6	209·0
August	276·5	229·4	196·0	147·6	(204·6)	164·3	153·6	102·1	187·3	240·7
September	291·7	235·2	193·8	195·7	(202·2)	137·2	163·7	84·8	204·4	250·8
October	276·7	206·2	183·8	199·4	(139·7)	137·2	142·5	114·9	221·6	248·2
November	242·2	174·2	168·1	188·1	(142·0)	58·7	77·7	0·0	222·5	248·2
December	203·3	131·8	1·9	162·7	0·0	0·3	0·0	0·2	149·5	0·3

	1971	1972	1973	1974	1975	1976	1	1	1	1
January	0·8	1·1	239·6	(123·2)	1·5	7·3				
February	4·8	5·0	233·7	6·6	5·9	6·9				
March	14·8	14·1	(38·2)	14·3	5·9	35·8				
April	44·5	35·6	(57·4)	65·4	23·0	88·8				
May	60·3	91·9	(71·4)	132·6	38·8	163·1				
June	73·2	165·7	(138·3)	190·0	141·6	272·8				
July	98·5	241·1	(156·9)	242·3	233·6	386·2				
August	99·2	315·7	(207·2)	268·2	319·4	473·7				
September	126·6	334·6	(234·3)	262·7	340·2	480·9				
October	129·9	344·5	(185·9)	186·7	252·4	409·2				
November	89·5	345·6	(182·9)	3·6	248·4	0·0				
December	30·1	294·8	(159·0)	1·5	0·2	0·0				

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